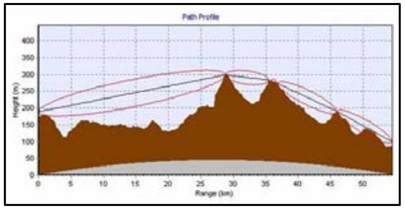
Wave Propagation over Irregular and Inhomogeneous Terrain



Mauro S. Assis - Fluminense Federal University

Jorge L. Cerqueira - Military Institute of Engineering

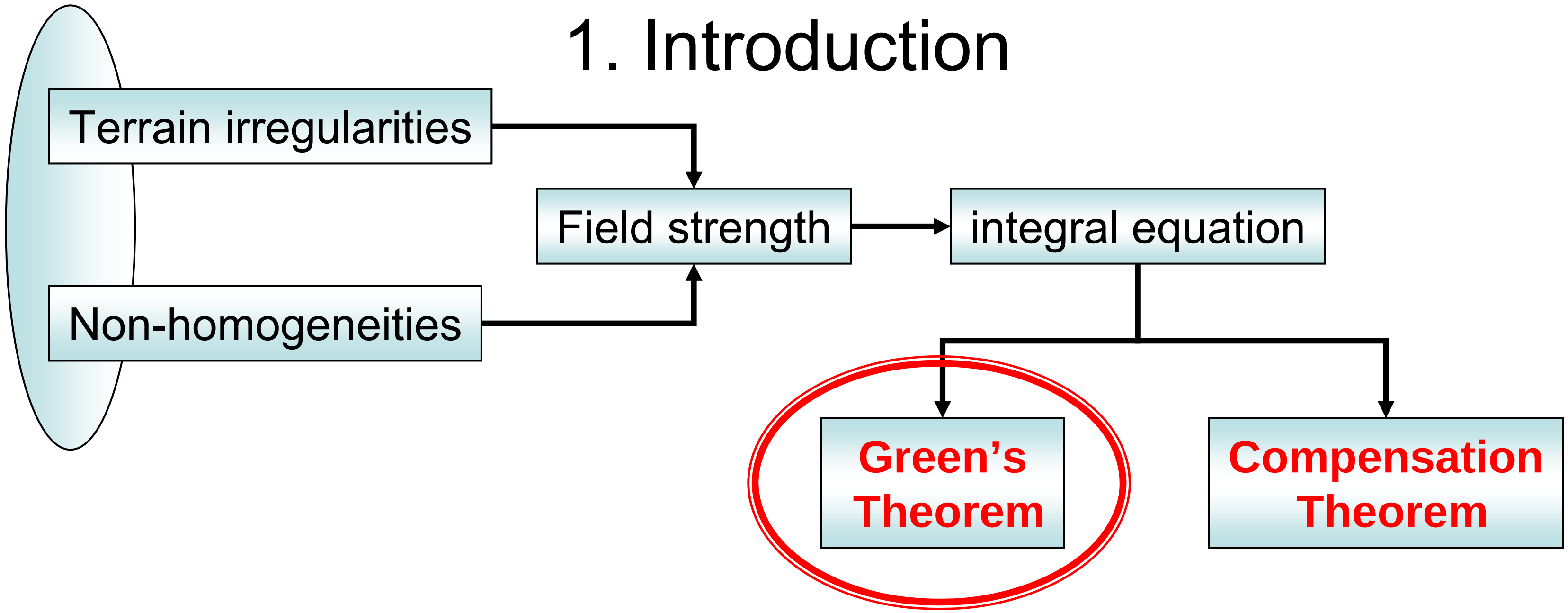
Presented by Ângelo Canavitsas

Outline

Abstract

- This paper deals with problem of radio wave over irregular and inhomogeneous earth.
- Two solutions based on the Green's theorem are described.
- An integral equation solved by numerical methods and a generalization of the classical residue series approach.
- Advantages and limitations of each solution are pointed out.

1. Introduction



- It should be pointed out that these two approaches are equivalent, leading to the same mathematical formulation.

1. Introduction - **Green's theorem**

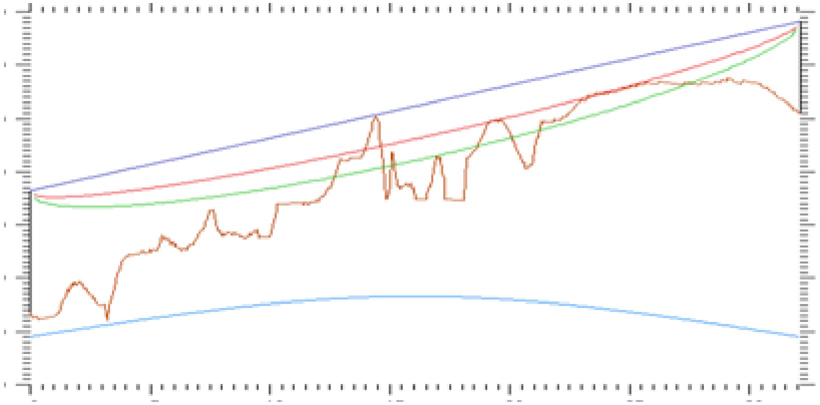
- This paper describes two solutions based on the **Green's theorem**, the integral equation [1] and the multiple residue series [2].

•**[1]** Hufford, G., "An integral equation approach to the problem of wave propagation over an irregular surface", Quarterly Applied Mathematics, vol. 9, n.4, pp. 391- , 1952.

•**[2]** Furutsu, K., " A systematic theory of wave propagation over irregular terrain", Radio Science, vol. 17, n.5, pp1037-1059,May, 1982.

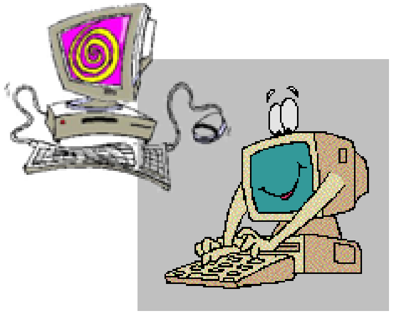
2. Integral equation - **Hufford [1]**

- In the integral equation derived by Hufford [1], the terrain is represented by a completely arbitrary profile along the great circle path and the electrical properties of the medium can vary continuously.
- In other words, it can deal with complicated variations of terrain without introducing approximations based on the geometry of problem.



2. Integral equation - **Hufford [1]**

- However, this solution has some limitations such as the need of a great deal of computer storage, a numerical instability for high frequencies and to the fact that steep slopes and cliffs cannot be included.



2. Integral Equation

Field Strength

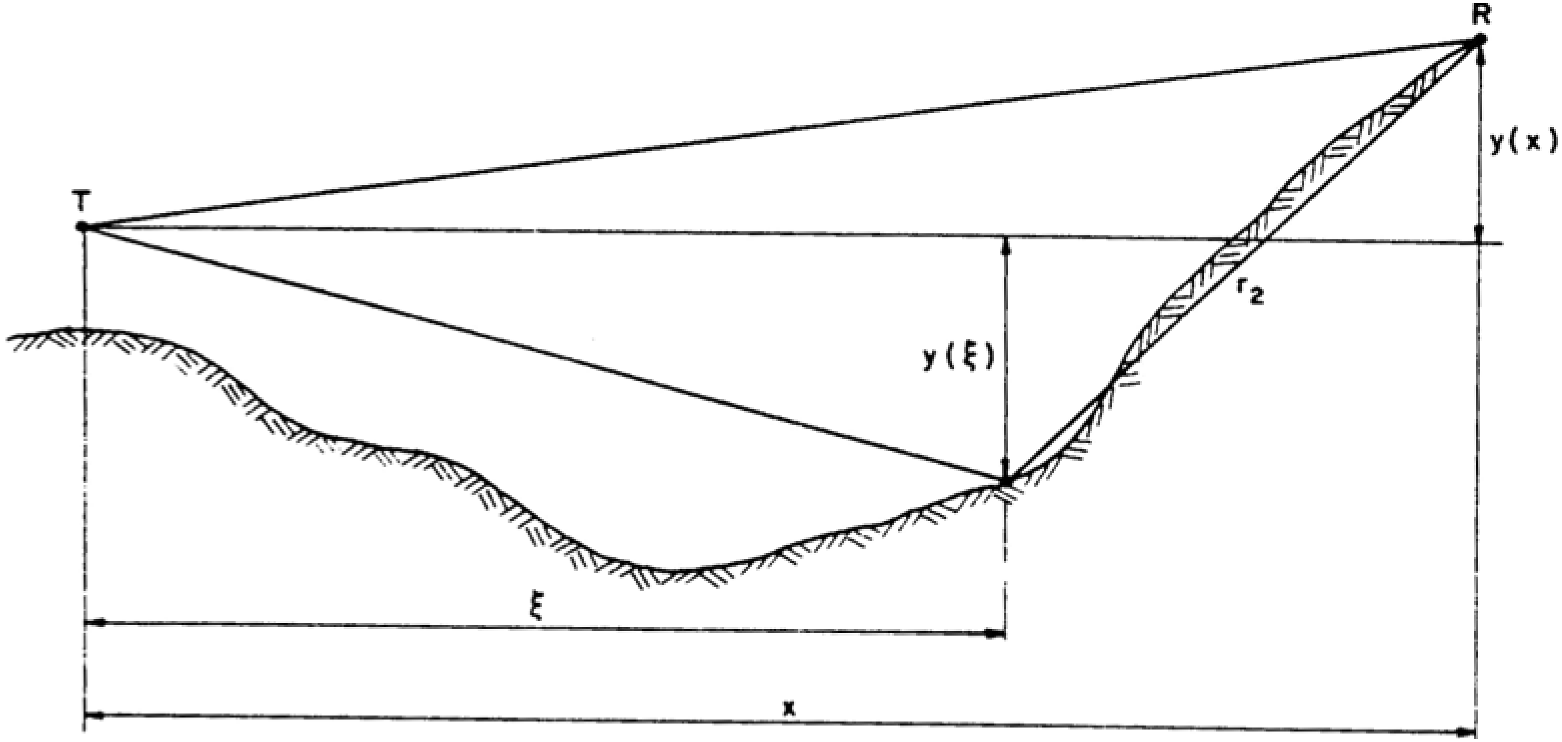
Terrain profile factor

$$\boxed{f(x)} = \boxed{W(x,0)} - \sqrt{\frac{j}{\lambda}} \int_0^x f(\xi) e^{-jkw(x,\xi)} \{ y'(\xi) W(x,\xi) - \boxed{\frac{y(x) - y(\xi)}{x - \xi}} \boxed{+ [\Delta(\xi) - \Delta_r]} W(x,\xi) \} \left[\frac{x}{\xi(x - \xi)} \right]^{1/2} d\xi$$

Flat earth attenuation function

Mixed-path factor

2. Integral Equation
Geometry for the integral equation



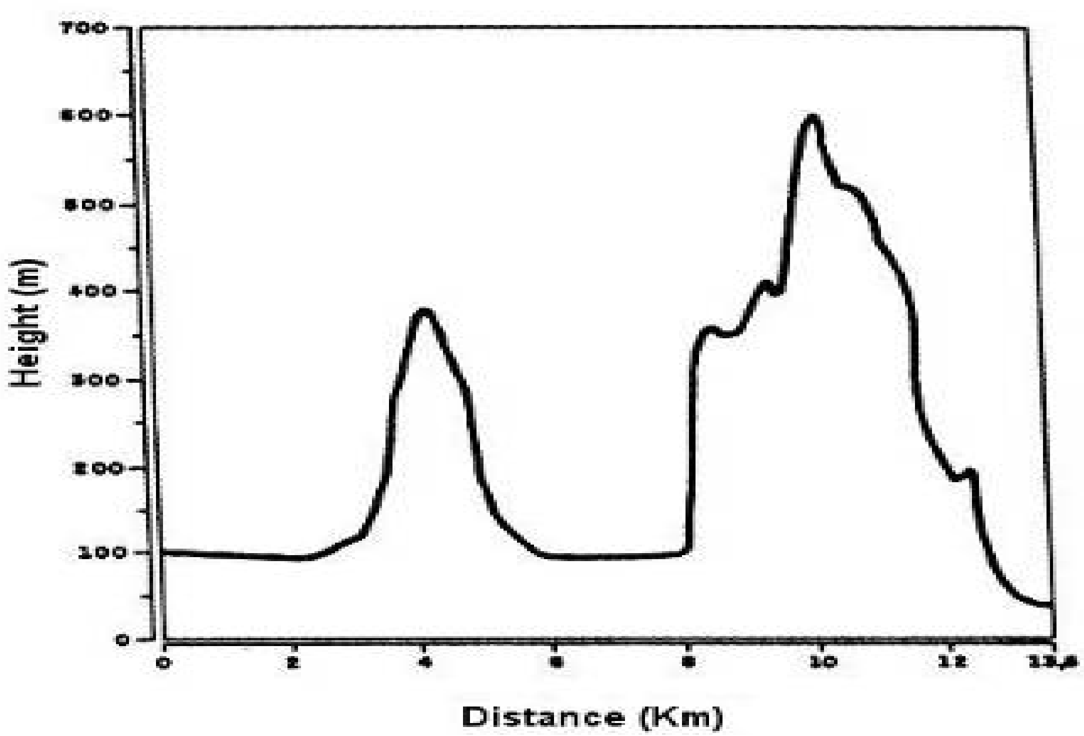
More details are available in Ott, R.H., L.E. Vogler and G.H. Hufford [5] and DeMinco [6].

[5] Ott, R.H., L.E. Vogler and G.H. Hufford, "Ground-wave propagation over irregular inhomogeneous terrain: Comparisons of calculations and measurements", IEEE Trans. on Antennas and Propagation, volume AP-37, n.2, pp.283-285, March, 1979;

[6] DeMinco, N. "Propagation prediction techniques and antenna modeling (150 to 1705 kHz) for intelligent transportation systems (ITS) broadcast applications, IEEE Antennas and Propagation Magazine, vol. 42, n.4, pp. 9-34, August 2000;

2. Integral Equation
Path profile for integral equation

- The profile corresponding to path 13.6 km long.
- Operating in the frequency of 10.254 MHz.
- Shows a better agreement with Δx = 50 m.
- This value is 1.6λ and proves that the maximum Δx is around one wavelength.

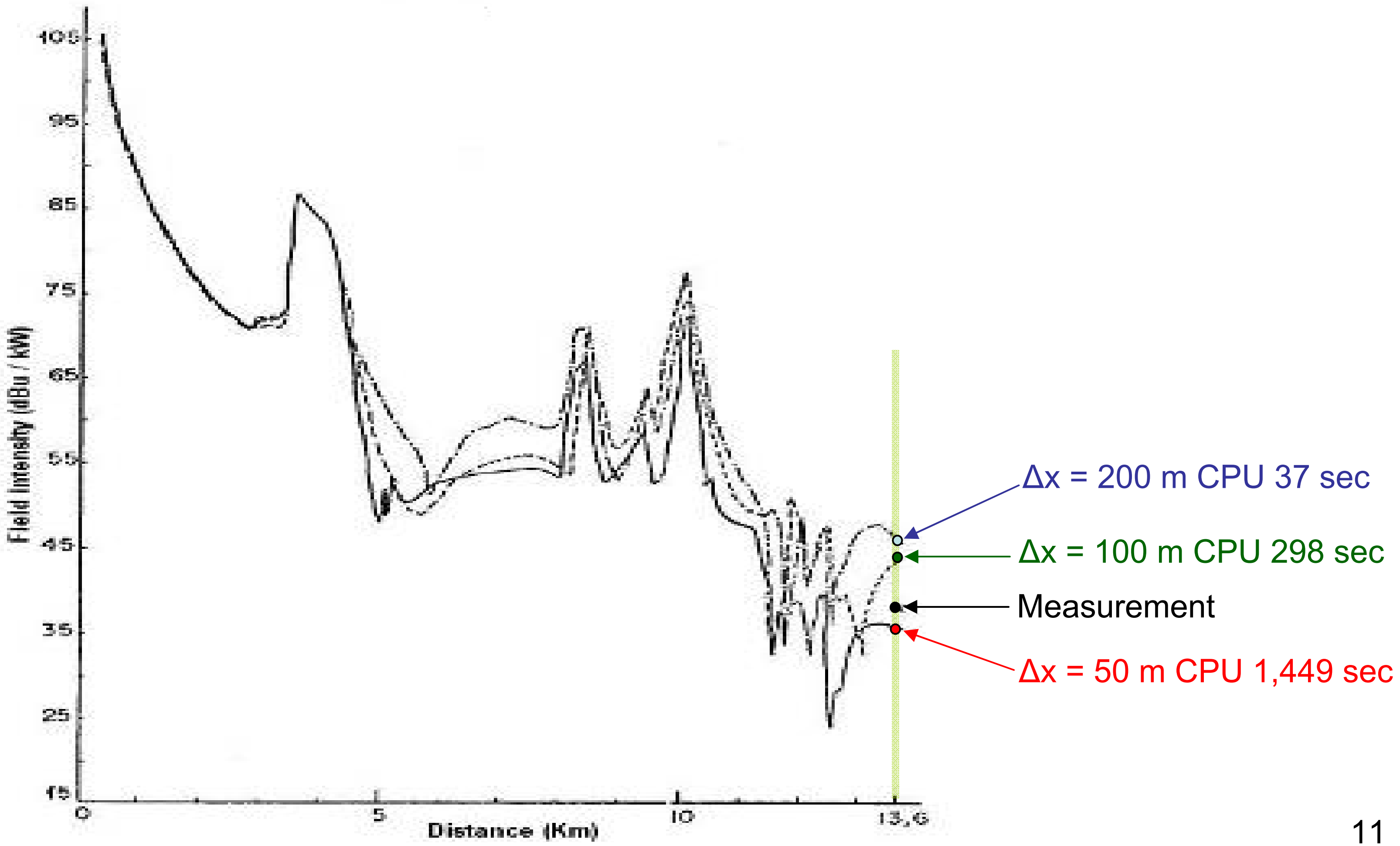


The example is given in [7]

- **[7] Assis, M.S. and J.L. Cerqueira**, "Diffraction by terrain irregularities" International Conference on Radio Science – ICRS 2008, Jodhpur, India, February, 2008.

2. Integral Equation

Computer time and measured point

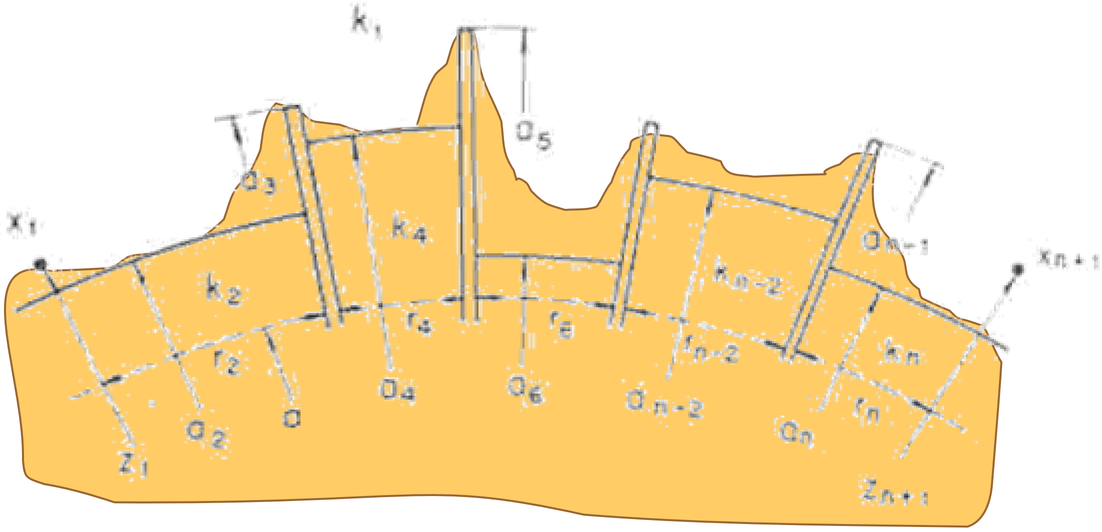


3. Furutsu Solution

- **Furutsu [2]** has developed a theory of wave propagation over a multi-section terrain. Each section can have different electrical properties and different heights and the transmitter and receiver can be elevated.

3. Furutsu Solution

- This theory can be used to model mixed paths, ridges, bluffs, coastlines with cliffs, islands, etc. In this context, Furutsu approach complements the integral solution. A practical limitation refers to the number of sections to be modeled before the method becomes too complex.



4. Comments

- Under the practical point of view, the diffraction by terrain is normally considered for two specific models **[8]**: diffraction over a smooth spherical earth and diffraction by single or isolated obstacles.
- In spite of solving important engineering problems, these models do not provide a general solution for the propagation over a rolling terrain or when the terrain discontinuities should be taken into account.
- This question is being considered in the working program of the ITU-R Rapporteur Group 3J-5/1 [9].

[8] UIT-R, "Propagation by diffraction", Recommendation ITU-R P.526-9, Geneva, 2005;

4. Comments (Cont.)

- It should be mentioned that the field intensity in the profile used in the previous example was also calculated by the Assis method [10] for multiple diffraction and the result was the same to the integral equation.
- On the other hand, as it was shown by Ott and Berry [3], for the case of a smooth and homogeneous Earth there is a close agreement between values evaluated by the integral equation (1) and by the residue series [11].
- Consequently, the integral equation can be seen as the bridge for connecting the above limiting cases.

[3] Ott, R.H. and L. A. Berry, "An alternative integral equation for propagation over irregular terrain", Radio Science, vol. 5, n. 5,pp.767-771, May, 1970.

[10] Assis, M.S., "A simplified solution to the problem of multiple diffraction over rounded obstacles", IEEE Transactions on Antennas and Propagation, volume AP-19, n.2, pp. 291-295, March, 1971

[11] Bremmer, H., "Terrestrial Radio Waves", Elsevier Publishing Company, Amsterdam, 1949.

5. Concluding Remarks

- In spite of its complexity, the integral equation provides a general solution to the problem of radio wave propagation over an irregular and inhomogeneous terrain.
- It attends the requirement to be a connection between the limiting cases of propagation over a smooth earth and the diffraction by several isolated obstacles.
- Additionally, it has an easy physical interpretation where the terms corresponding to terrain slope and terrain non-homogeneities are clearly defined.

5. Concluding Remarks (Cont.)

- Furutsu solution can also be used as a complement to the integral equation.
- The only restriction is the number of sections to be modeled before the method becomes too complex.
- For instance, numerical calculations evaluated by **Furutsu [2;12-14]** are limited to three sections.
- Anyway, considering that the solutions described here are quite rigorous, they constitute two powerful tools to solve the problem of radio wave propagation.

Thank you!

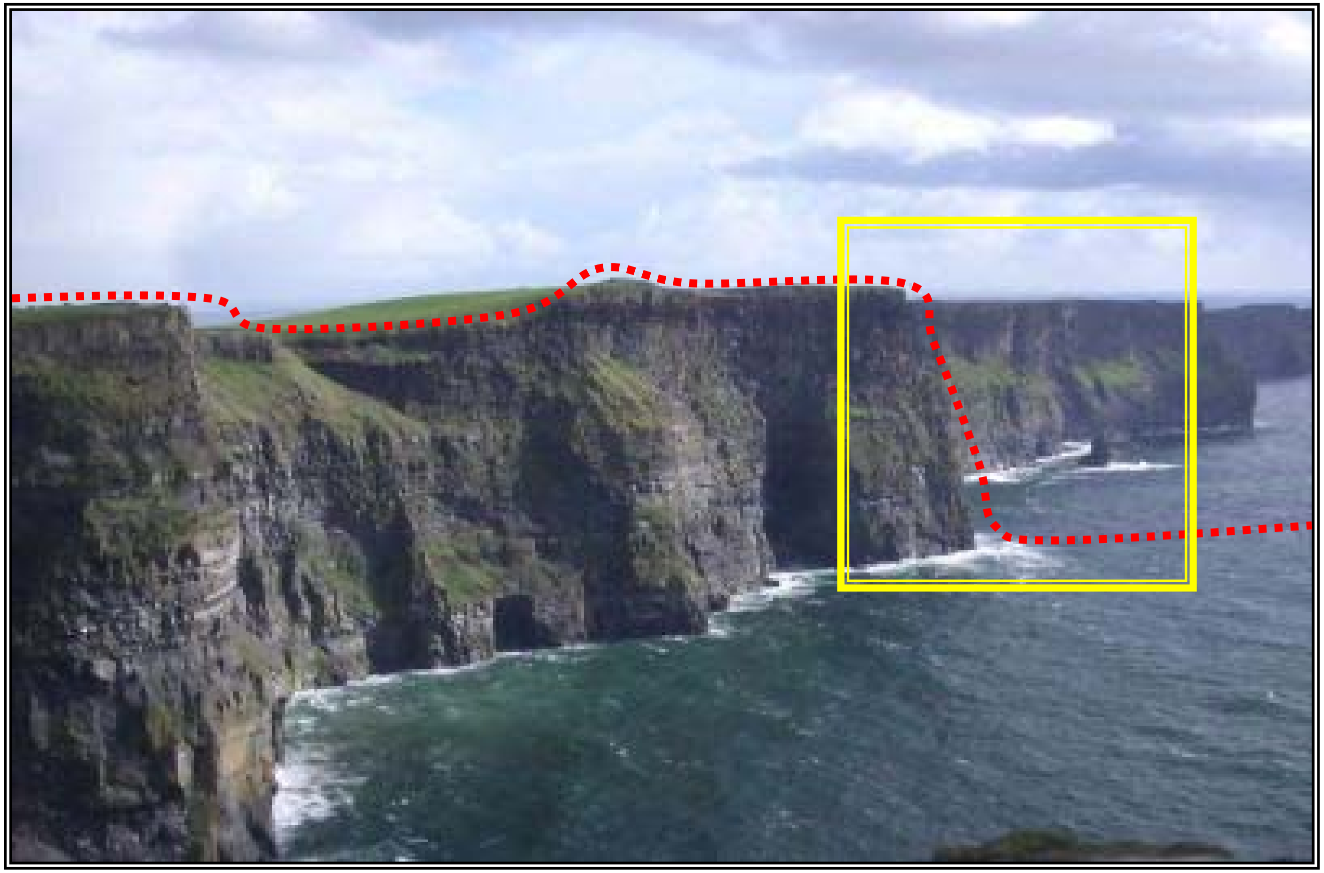
Mauro S. Assis
Fluminense Federal University – Rio de Janeiro - RJ
msassis@openlink.com.br

Jorge L. Cerqueira
Military Institute of Engineering - Rio de Janeiro – RJ
jlcerq@ime.eb.br

References

- **[12] Furutsu**, K., “On the theory of radio wave propagation over inhomogeneous earth”, Journal of Research of the NBS, volume 67D, n.1, pp. 39-62, January-February, 1963.
- **[13] Furutsu**, K., R.E. Wilkerson and R.F. Hartmann, “Some numerical results based on the theory of radio wave propagation over inhomogeneous earth”, Journal of Research of the NBS, volume 68D, n.7, pp. 827-846, July, 1964.
- **[14] Furutsu**, K. and K. Wilkerson, “Obstacle gain in radio-wave propagation over inhomogeneous earth”, Proceedings of the IEE, volume 117, n.5, pp. 887-893, May, 1970.

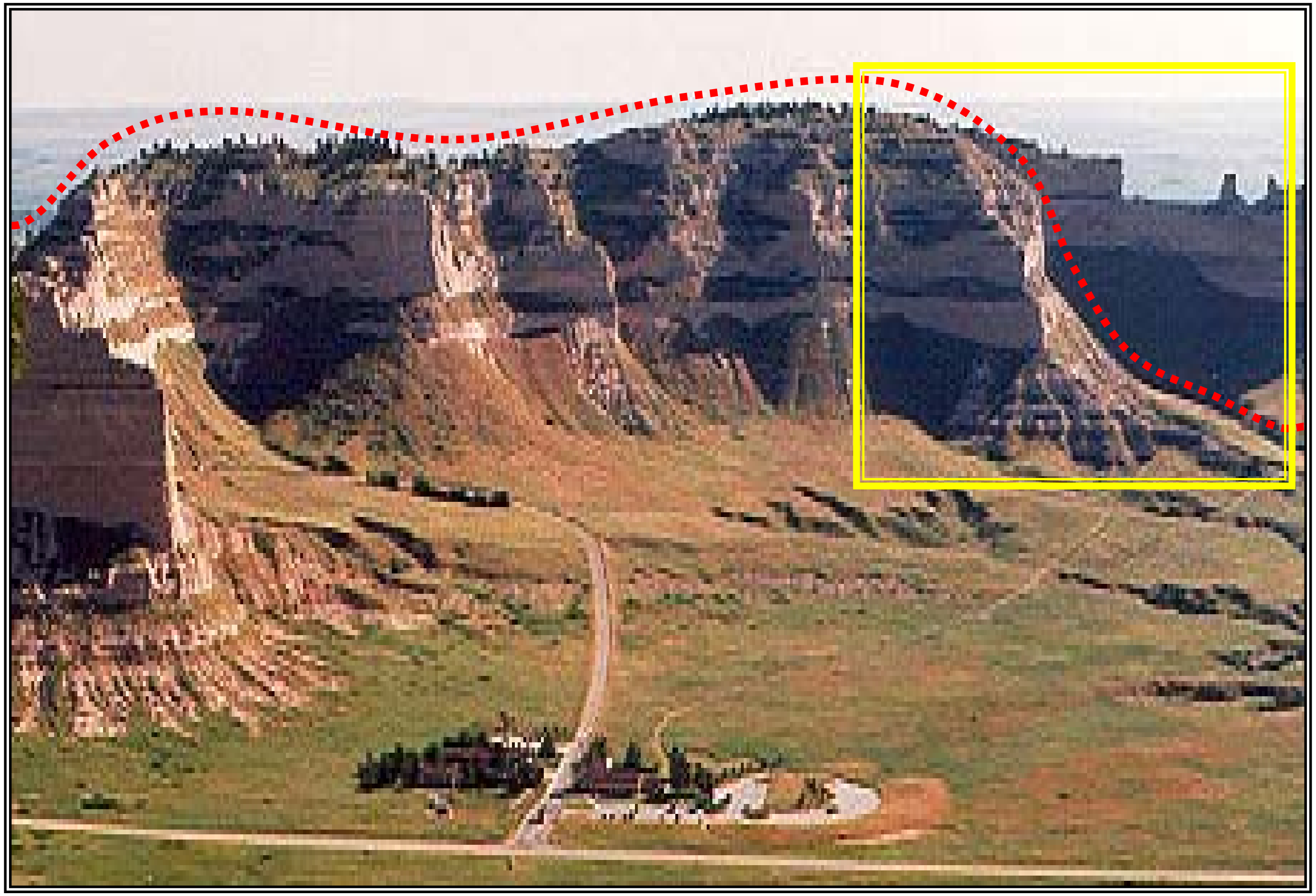
e.g. Cliffs



- **Cliffs of Moher**

  Situated in County Clare and bordering the Burren Area, the Cliffs of Moher are one of Ireland's top visitor sites. Looming ove County Clare's west coast, the Cliffs stretch for 8 kilometers and 214 meters over the waters of the Atlantic ocean.

e.g. Bluff



- **Scotts Bluff National Monument**

  A prominent natural landmark for emigrants on the Oregon Trail, Scotts Bluff, Mitchell Pass and the adjacent prairie lands are set aside in a 3,000 acre national monument.

e.g. Ridges

- **Coastal Ridges, Russian Ridge Open Space Preserve**